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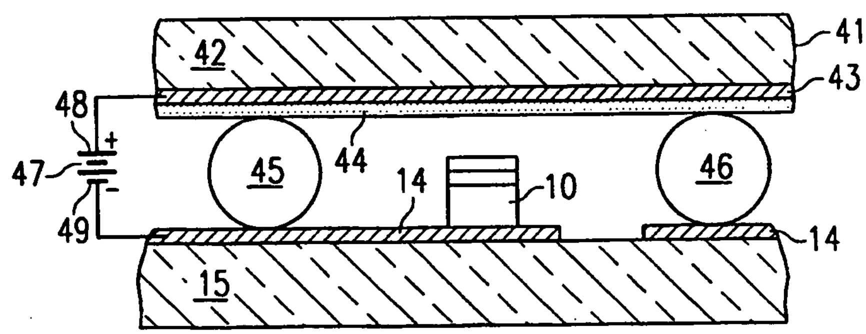
(57) Abstract

A field emission cathode includes a layer of conductive material (14) and a layer of amorphic diamond film (12), functioning as a low effective work-function material, deposited over the conductive material to form emission sites. The emission sites each contain at least two sub-regions having differing electron affinities.



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AMORPHIC DIAMOND FILM FLAT FIELD EMISSION CATHODE

RELATED APPLICATION

This application is a continuation-in-part of Serial No. 07/851,701, which was filed on March 16, 1992, entitled "Flat Panel Display Based on Diamond Thin Films" which application is hereby incorporated herein by reference.

TECHNICAL FIELD OF THE INVENTION

This invention relates, in general, to flat field emission cathodes and, more particularly, to such cathodes which employ an amorphic diamond film having a plurality of emission sites situated on a flat emission surface.

BACKGROUND OF THE INVENTION

Field emission is a phenomenon which occurs when an electric field proximate the surface of an emission material narrows a width of a potential barrier existing at the surface of the emission material. This allows a quantum tunnelling effect to occur, whereby electrons cross through the potential barrier and are emitted from the material. This is as opposed to thermionic emission, whereby thermal energy within an emission material is sufficient to eject electrons from the material. Thermionic emission is a classical phenomenon, whereas field emission is a quantum mechanical phenomenon.

The field strength required to initiate field emission of electrons from the surface of a particular material depends upon that material's effective "work function." Many materials have a positive work function and thus require a relatively intense electric field to bring about field emission. Some materials do, in fact, have a low work function, or even a negative electron affinity, and thus do not require intense fields for emission to occur. Such materials may be deposited as a thin film onto a conductor, resulting in a cathode with a relatively low threshold voltage required to produce electron emissions.

In prior art devices, it was desirable to enhance field emission of electrons by providing for a cathode geometry which focussed electron emission at a single, relatively sharp point at a tip of a conical cathode (called a micro-tip cathode). These micro-tip cathodes, in conjunction with extraction grids

proximate the cathodes, have been in use for years in field emission displays.

For example, U.S. Patent No. 4,857,799, which issued on August 15, 1989, to Spindt et al., is directed to a matrix-addressed flat panel display using field emission cathodes. The cathodes are incorporated into the display backing structure, and energize corresponding cathodoluminescent areas on a face plate. The face plate is spaced 40 microns from the cathode arrangement in the preferred embodiment, and a vacuum is provided in the space between the plate and cathodes. Spacers in the form of legs interspersed among the pixels maintain the spacing, and electrical connections for the bases of the cathodes are diffused sections through the backing structure. Spindt et al. employ a plurality of micro-tip field emission cathodes in a matrix arrangement, the tips of the cathodes aligned with apertures in an extraction grid over the cathodes. With the addition of an anode over the extraction grid, the display described in Spindt et al. is a triode (three terminal) display.

Unfortunately, micro-tips employ a structure which is difficult to manufacture, since the micro-tips have fine geometries. Unless the micro-tips have a consistent geometry throughout the display, variations in emission from tip to tip will occur, resulting in unevenness in illumination of the display. Furthermore, since manufacturing tolerances are relatively tight, such micro-tip displays are expensive to make.

For years, others have directed substantial effort toward solving the problem of creating cathodes which

can be mass manufactured to tight tolerances, allowing them to perform with accuracy and precision. Another object of some of these prior art inventions was that they made use of emission materials having a relatively low effective work function so as to minimize extraction field strength.

One such effort is documented in U.S. Patent No. 3,947,716, which issued on March 30, 1976, to Fraser, Jr. et al., directed to a field emission tip on which a metal adsorbent has been selectively deposited. In a vacuum, a clean field emission tip is subjected to heating pulses in the presence of an electrostatic field to create thermal field build up of a selected plane. Emission patterns from this selected plane are observed, and the process of heating the tip within the electrostatic field is repeated until emission is observed from the desired plane. The adsorbent is then evaporated onto the tip. The tip constructed by this process is selectively faceted with the emitting planar surface having a reduced work function and the non-emitting planar surface as having an increased work function. A metal adsorbent deposited on the tip so prepared results in a field emitter tip having substantially improved emission characteristics. Unfortunately, as previously mentioned, such micro-tip cathodes are expensive to produce due to their fine geometries. Also, since emission occurs from a relatively sharp tip, emission is still somewhat inconsistent from one cathode to another. Such disadvantages become intolerable when many cathodes are employed in great numbers such as in a flat panel display for a computer.

As is evident in the above-described cathode structure, an important attribute of good cathode design is to minimize the work function of the material constituting the cathode. In fact, some substances such as alkali metals and elemental carbon in the form of diamond crystals display a low effective work function. Many inventions have been directed to finding suitable geometries for cathodes employing negative electron affinity substances as a coating for the cathode.

For instance, U.S. Patent No. 3,970,887, which issued on July 20, 1976, to Smith et al., is directed to a microminiature field emission electron source and method of manufacturing the same wherein a single crystal semiconductor substrate is processed in accordance with known integrated microelectronic circuit techniques to produce a plurality of integral, single crystal semiconductor raised field emitter tips at desired field emission cathode sites on the surface of a substrate in a manner such that the field emitters tips are integral with the single crystal semiconductor substrate. An insulating layer and overlying conductive layer may be formed in the order named over the semiconductor substrate and provided with openings at the field emission locations to form micro-anode structures for the field emitter tip. By initially appropriately doping the semiconductor substrate to provide opposite conductivity-type regions at each of the field emission locations and appropriately forming the conductive layer, electrical isolation between the several field emission locations can be obtained. Smith et al. call for a sharply-tipped cathode. Thus, the cathode disclosed in Smith et al. is subject to the same disadvantages as Fraser, Jr. et al..

U.S. Patent No. 4,307,507, which issued on December 29, 1981, to Gray et al., is directed to a method of manufacturing a field-emitter array cathode structure in which a substrate of single crystal material is selectively masked such that the unmasked areas define islands on the underlying substrate. The single crystal material under the unmasked areas is orientation-dependent etched to form an array of holes whose sides intersect at a crystal graphically sharp point.

U.S. Patent No. 4,685,996, which issued on August 11, 1987, to Busta et al., is also directed to a method of making a field emitter and includes an anisotropically etched single crystal silicon substrate to form at least one funnel-shaped protrusion on the substrate. The method of manufacturing disclosed in Busta et al. provides for a sharp-tipped cathode.

Sharp-tipped cathodes are further described in U.S. Patent No. 4,885,636, which issued on August 8, 1989, to Busta et al..

Yet another sharp-tipped emission cathode is disclosed in U.S. Patent No. 4,964,946, which issued on October 23, 1990, to Gray et al.. Gray et al. disclose a process for fabricating soft-aligned field emitter arrays using a soft-leveling planarization technique, e.g. a spin-on process.

Even though they employ low effective work-function materials to advantage, sharp-tipped cathodes have fundamental problems when employed in a flat panel graphic display environment, as briefly mentioned above. First, they are relatively expensive to manufacture. Second, they are hard to manufacture with

great consistency. That is, electron emission from sharp-tipped cathodes occurs at the tip. Therefore, the tip must be manufactured with extreme accuracy such that, in a matrix of adjacent cathodes, some cathodes do not emit electrons more efficiently than others, thereby creating an uneven visual display. In other words, the manufacturing of cathodes must be made more reliable so as to minimize the problem of inconsistencies in brightness in the display along its surface.

In Serial No. 07/851,701, which was filed on March 16, 1992, and entitled "Flat Panel Display Based on Diamond Thin Films," an alternative cathode structure was first disclosed. Serial No. 07/851,701 discloses a cathode having a relatively flat emission surface as opposed to the aforementioned micro-tip configuration. The cathode, in its preferred embodiment, employs a field emission material having a relatively low effective work function. The material is deposited over a conductive layer and forms a plurality of emission sites, each of which can field-emit electrons in the presence of a relatively low intensity electric field.

Flat cathodes are much less expensive and difficult to produce in quantity because the fine, micro-tip geometry has been eliminated. The advantages of the flat cathode structure was discussed at length therein. The entirety of Serial No. 07/851,701, which is commonly assigned with the present invention, is incorporated herein by reference.

A relatively recent development in the field of materials science has been the discovery of amorphic

diamond. The structure and characteristics of amorphic diamond are discussed at length in "Thin-Film Diamond," published in the Texas Journal of Science, vol. 41, no. 4, 1989, by C. Collins et al.. Collins et al. describe a method of producing amorphic diamond film by a laser deposition technique. As described therein, amorphic diamond comprises a plurality of micro-crystallites, each of which has a particular structure dependent upon the method of preparation of the film. The manner in which these micro-crystallites are formed and their particular properties are not entirely understood.

Diamond has a negative election affinity. That is, only a relatively low electric field is required to distort the potential barrier present at the surface of diamond. Thus, diamond is a very desirable material for use in conjunction with field emission cathodes. In fact, the prior art has employed crystalline diamond films to advantage as an emission surface on micro-tip cathodes.

In "Enhanced Cold-Cathode Emission Using Composite Resin-Carbon Coatings," published by S. Bajic and R.V. Latham from the Department of Electronic Engineering and Applied Physics, Aston University, Aston Triangle, Burmingham B4 7ET, United Kingdom, received May 29, 1987, a new type of composite resin-carbon field-emitting cathode is described which is found to switch on at applied fields as low as approximately 1.5 MV m^{-1}, and subsequently has a reversible I-V characteristic with stable emission currents of > or = 1 mA at moderate applied fields of typically < or = 8 MV m^{-1}. A direct electron emission imaging technique has shown that the total externally recorded current

stems from a high density of individual emission sites randomly distributed over the cathode surface. The observed characteristics have been qualitatively explained by a new hot-electron emission mechanism involving a two-stage switch-on process associated with a metal-insulator-metal-insulator-vacuum (MIMIV) emitting regime. However, the mixing of the graphite powder into a resin compound results in larger grains, which results in fewer emission sites since the number of particles per unit area is small. It is preferred that a larger amount of sites be produced to produce a more uniform brightness from a low voltage source.

In "Cold Field Emission From CVD Diamond Films Observed In Emission Electron Microscopy," published by C. Wang, A. Garcia, D.C. Ingram, M. Lake and M.E. Kordesch from the Department of Physics and Astronomy and the Condensed Matter and Surface Science Program at Ohio University, Athens, Ohio on June 10, 1991, there is described thick chemical vapor deposited "CVD" polycrystalline diamond films having been observed to emit electrons with an intensity sufficient to form an image in the accelerating field of an emission microscope without external excitation. The individual crystallites are of the order of 1-10 microns. The CVD process requires 800°C for the depositing of the diamond film. Such a temperature would melt a glass substrate.

The prior art has failed to: (1) take advantage of the unique properties of amorphic diamond; (2) provide for field emission cathodes having a more diffused area from which field emission can occur; and (3) provide for a high enough concentration of emission sites (i.e., smaller particles or crystallites) to produce a

more uniform electron emission from each cathode site, yet require a low voltage source in order to produce the required field for the electron emissions.

SUMMARY OF THE INVENTION

The prior art has failed to recognize that amorphic diamond, which has physical qualities which differ substantially from other forms of diamond, makes a particularly good emission material. Serial No. 07/851,701 was the first to disclose use of amorphic diamond film as an emission material. In fact, in the preferred embodiment of the invention described therein, amorphic diamond film was used in conjunction with a flat cathode structure to result in a radically different field emission cathode design.

The present invention takes the utilization of amorphic diamond a step further by depositing the amorphic diamond in such a manner so that a plurality of diamond micro-crystallite regions are deposited upon the cathode surface such that at each region (pixel) there are a certain percentage of the crystals emerging in an SP^2 configuration and another percentage of the crystals emerging in an SP^3 configuration. The numerous SP^2 and SP^3 configurations at each region result in numerous discontinuities or interface boundaries between the configurations, with the SP^2 and SP^3 crystallites having different electron affinities.

Accordingly, to take advantage of the above-noted opportunities, it is a primary object of the present invention to provide an independently addressable cathode, comprising a layer of conductive material and a layer of amorphic diamond film, functioning as a low effective work-function material, deposited over the conductive material, the amorphic diamond film comprising a plurality of distributed localized electron emission sites, each sub-site having a

plurality of sub-regions with differing electron affinities between sub-regions.

In a preferred embodiment of the present invention, the amorphic diamond film is deposited as a relatively flat emission surface. Flat cathodes are easier and, therefore, less expensive to manufacture and, during operation of the display, are easier to control emission therefrom.

A technical advantage of the present invention is to provide a cathode wherein emission sites have electrical properties which include discontinuous boundaries with differing electron affinities.

Another technical advantage of the present invention is to provide a cathode wherein emission sites contain dopant atoms.

Yet another technical advantage of the present invention is to provide a cathode wherein a dopant atom is carbon.

Yet a further technical advantage of the present invention is to provide a cathode wherein emission sites each have a plurality of bonding structures.

Still yet another technical advantage of the present invention is to provide a cathode wherein one bonding structure at an emission site is SP^3.

Still a further technical advantage of the present invention is to provide a cathode wherein each emission site has a plurality of bonding orders, one of which is SP^3.

Another technical advantage of the present invention is to provide a cathode wherein emission sites contain dopants of an element different from a low effective work-function material. In the case of use of amorphic diamond as the low effective work-function material, the dopant element is other than carbon.

Still another technical advantage of the present invention is to provide a cathode wherein emission sites contain discontinuities in crystalline structure. The discontinuities are either point defects, line defects or dislocations.

The present invention further includes novel methods of operation for a flat panel display and use of amorphic diamond as a coating on an emissive wire screen and as an element within a cold cathode fluorescent lamp.

In the attainment of the above-noted features and advantages, the preferred embodiment of the present invention is an amorphic diamond film cold-cathode comprising a substrate, a layer of conductive material, an electronically resistive pillar deposited over the substrate and a layer of amorphic diamond film deposited over the conductive material, the amorphic diamond film having a relatively flat emission surface comprising a plurality of distributed micro-crystallite electron emission sites having differing electron affinities.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may b better understood.

Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a cross-sectional representation of the cathode and substrate of the present invention;

FIGURE 2 is a top view of the cathode of the present invention including emission sites;

FIGURE 3 is a more detailed representation of the emission sites of FIGURE 2;

FIGURE 4 is a cross-sectional view of a flat panel display employing the cathode of the present invention;

FIGURE 5 is a representation of a coated wire matrix emitter;

FIGURE 6 is a cross-sectional view of a coated wire;

FIGURE 7 is a side view of a florescent tube employing the coated wire of FIGURE 6;

FIGURE 8 is a partial section end view of the fluorescent tube of FIGURE 7; and

FIGURE 9 is a computer with a flat-panel display that incorporates the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to FIGURE 1, shown is a cross-sectional representation of the cathode and substrate of the present invention. The cathode, generally designated 10, comprises a resistive layer 11, a low effective work-function emitter layer 12 and an intermediate metal layer 13. The cathode 10 sits on a cathode conductive layer 14 which, itself, sits on a substrate 15. The structure and function of the layers 11, 12, 13 of the cathode 10 and the relationship of the cathode 10 to conductive layer 14 and substrate 15 are described in detail in related application Serial No. 07/851,701, which is incorporated herein by reference.

Turning now to FIGURE 2, shown is a top view of the cathode 10 of FIGURE 1. The emitter layer 12 is, in the preferred embodiment of the present invention, amorphic diamond film comprising a plurality of diamond micro-crystallites in an overall amorphic structure. The micro-crystallites result when the amorphic diamond material is deposited on the metal layer 13 by means of laser plasma deposition, chemical vapor deposition, ion beam deposition, sputtering, low temperature deposition (less than 500 degrees Centigrade), evaporation, cathodic arc evaporation, magnetically separated cathodic arc evaporation, laser acoustic wave deposition or similar techniques or a combination of the above whereby the amorphic diamond film is deposited as a plurality of micro-crystallites. One such process is discussed within "Laser Plasma Source of Amorphic Diamond," published by the American Institute of Physics, January 1989, by C.B. Collins, et al.

The micro-crystallites form with certain atomic structures which depend on environmental conditions during deposition and somewhat on chance. At a given environmental pressure and temperature, a certain percentage of crystals will emerge in an SP^2 (two-dimensional bonding of carbon atoms) configuration. A somewhat smaller percentage, however, will emerge in an SP^3 (three-dimensional bonding) configuration. The electron affinity for diamond micro-crystallites in an SP^3 configuration is less than that for carbon or graphite micro-crystallites in an SP^2 configuration. Therefore, micro-crystallites in the SP^3 configuration have a lower electron affinity, making them "emission sites." These emission sites (or micro-crystallites with an SP^3 configuration) are represented in FIGURE 2 as a plurality of black spots in the emitter layer 12.

The flat surface is essentially a microscopically flat surface. A particular type of surface morphology, however, is not required. But, small features typical of any polycrystalline thin film may improve emission characteristics because of an increase in enhancement factor. Certain micro-tip geometries may result in a larger enhancement factor and, in fact, the present invention could be used in a micro-tip or "peaked" structure.

Turning now to FIGURE 3, shown is a more detailed view of the micro-crystallites of FIGURE 2. Shown is a plurality of micro-crystallites 31, 32, 33, 34, for example. Micro-crystallites 31, 32, 33 are shown as having an SP^2 configuration. Micro-crystallite 34 is shown as having an SP^3 configuration. As can be seen

in FIGURE 3, micro-crystallite 34 is surrounded by micro-crystallites having an SP^2 configuration.

There are a very large number of randomly distributed localized emission sites per unit area of the surface. These emission sites are characterized by different electronic properties of that location from the rest of the film. This may be due to one or a combination of the following conditions:

1) presence of a doping atom (such as carbon) in the amorphic diamond lattice;

2) a change in the bonding structure from SP^2 to SP^3 in the same micro-crystallite;

3) a change in the order of the bonding structure in the same micro-crystallite;

4) an impurity (perhaps a dopant atom) of an element different from that of the film material;

5) an interface between the various micro-crystallites;

6) impurities or bonding structure differences occurring at the micro-crystallite boundary; or

7) other defects, such as point or line defects or dislocations.

The manner of creating each of the above conditions during production of the film is well known in the art.

One of the above conditions for creating differences in micro-crystallites is doping. Doping of amorphic diamond thin film can be accomplished by interjecting elemental carbon into the diamond as it is being deposited. When doping with carbon, micro-crystallites of different structures will be created statistically. Some micro-crystallites will be n-type. Alternatively, a non-carbon dopant atom could be used,

depending upon the desired percentage and characteristics of emission sites. Fortunately, in the flat panel display environment, cathodes with as few as 1 emission site will function adequately. However, for optimal functioning, 1 to 10 n-type micro-crystallites per square micron are desired. And, in fact, the present invention results in micro-crystallites less than 1 micron in diameter, commonly 0.1 micron.

Emission from the cathode 10 of FIGURE 1 occurs when a potential difference is impressed between the cathode 10 and an anode (not shown in FIGURE 1) which is separated by some small distance from the cathode 10. Upon impression of this potential, electrons are caused to migrate to the emission layer 12 of the cathode 10.

In the example that follows, the condition that will be assumed to exist to create micro-crystallites of different work function will be a change in the bonding structure from SP^2 to SP^3 in the same micro-crystallite (condition 3 above). With respect to the emission sites shown in FIGURES 2 and 3, micro-crystallites having an SP^3 configuration have a lower work-function and electron affinity than micro-crystallites having an SP^2 configuration. Therefore, as voltage is increased between the cathode 10 and anode (not shown), the voltage will reach a point at which the SP^3 micro-crystallites will begin to emit electrons. If the percentage of SP^3 micro-crystallites on the surface of the cathode 10 is sufficiently high, then emission from the SP^3 micro-crystallites will be sufficient to excite the anode (not shown), without having to raise voltage levels to a magnitude sufficient for emission to occur from the SP^2 micro-

crystallites. Accordingly, by controlling pressure, temperature and method of deposition of the amorphic diamond film in a manner which is well-known in the art, SP^3 micro-crystallites can be made a large enough percentage of the total number of micro-crystallites to produce sufficient electron emission.

Turning now to FIGURE 4, shown is a cross-sectional view of a flat panel display employing the cathode of the present invention. The cathode 10, still residing on its cathode conductive layer 14 and substrate 15 as in FIGURE 1, has been mated to an anode, generally designated 41 and comprising a substrate 42, which in the preferred embodiment is glass. The substrate 42 has an anode conductive layer 43 which, in the preferred embodiment, is an indium tin oxide layer. Finally, a phosphor layer 44 is deposited on the anode conductive layer to provide a visual indication of electron flow from the cathode 10. In other words, when a potential difference is impressed between the anode 41 and the cathode 10, electrons flowing from the cathode 10 will flow toward the anode conductive layer 43 but, upon striking the phosphor layer 44, will cause the phosphor layer to emit light through the glass substrate 42, thereby providing a visual display of a type desirable for use in conjunction with computers or other video equipment. The anode 41 is separated by insulated separators 45, 46 which provide the necessary separation between the cathode 10 and the anode 41. This is all in accordance with the device described in Serial No. 07/851,701.

Further, in FIGURE 4, represented is a voltage source 47 comprising a positive pole 48 and a negative pole 49. The positive pole is coupled from the source

47 to the anode conductiv layer 43, while the negative pole 49 is coupled from the source 47 to the cathode conductive layer 14. The device 47 impresses a potential difference between the cathode 10 and the anode 41, causing electron flow to occur between the cathode 10 and the anode 41 if the voltage impressed by the source 47 is sufficiently high.

Turning now to FIGURE 9, there is illustrated computer 90 with associated keyboard 93, disk drive 94, hardware 92 and display 91. The present invention may be employed within display 91 as a means for providing images and text. All that is visible of the present invention is anode 41.

Turning now to FIGURE 5, shown is a representation of a coated wire matrix emitter in the form of a wire mesh, generally designated 51. The wire mesh 51 comprises a plurality of rows and columns of wire which are electrically joined at their intersection points. The wire mesh 51 is then coated with a material having a low effective work-function and electron affinity, such as amorphic diamond, to thereby produce a wire mesh cathode for use in devices which previously used an uncoated wire or plate cathode and application of a high current and potential difference to produce incandescence and a flow of electrons from the mesh to an anode. By virtue of the amorphic diamond coating and its associated lower work function, incandescence is no longer necessary. Therefore, the wire mesh 51 cathode can be used at room temperature to emit electrons.

Turning now to FIGURE 6, shown is a cross-section of a wire which has been coated with a material having

a low work-function and electron affinity. The wire, designated 61, has a coating 62 which has been deposited by laser plasma deposition, or any one of the other well-known techniques listed above to thereby permit the coating 62 to act as a cold cathode in the same manner as the cathodes described in FIGURES 1-5.

Turning now to FIGURE 7, shown is one application of the wire 61 in which the coated wire 61 functions as a conductive filament and is surrounded by a glass tube 72, functioning as an anode and which has an electrical contact 73 to thereby produce a fluorescent tube. The tube functions in a manner which is analogous to the flat panel display application discussed in connection with FIGURES 1-5, that is, a potential difference is impressed between the wire 61 (negative) and the tube 72 sufficient to overcome the space-charge between the cathode wire 61 and the tube anode 72. Once the space-charge has been overcome, electrons will flow from emission site SP^3 micro-crystallites in the coating 62.

Turning now to FIGURE 8, shown is a partial section end view of the florescent tube 71 of FIGURE 7. Shown again are the wire 61 and the coating 62 of FIGURE 6 which, together, form a low effective work-function cathode in the fluorescent tube 71. The glass tube 72 of FIGURE 7 comprises a glass wall 81 on which is coated an anode conductive layer 82. The anode conductive layer 82 is electrically coupled to the electrical contact 73 of FIGURE 7. Finally, a phosphor layer 83 is deposited on the anode conductive layer 82. When a potential difference is impressed between the cathode wire 61 and the anode conductive layer 82, electrons are caused to flow between the emitter coating 82 and the anode conductive layer 82. However,

as in FIGURE 4, the electrons strike the phosphor layer 83 first, causing the phosphor layer 83 to emit photons through the glass wall 81 and outside the florescent tube 71, thereby providing light in a manner similar to conventional fluorescent tubes. However, because the fluorescent tube of FIGURES 7 and 8 employs a cathode having a low effective work-function emitter, such as amorphic diamond film, the fluorescent tube does not get warm during operation. Thus, the energy normally wasted in traditional fluorescent tubes in the form of heat is saved. In addition, since the heat is not produced, it need not be later removed by air conditioning.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

WHAT IS CLAIMED IS:

1. A cathode, comprising:

a layer of conductive material; and

a layer of low effective work-function material deposited over said conductive material, said low work-function material having an emission surface comprising a plurality of distributed localized electron emission sites.

2. The cathode as recited in claim 1 wherein said emission sites have electrical properties which are discontinuous from each other.

3. The cathode as recited in claim 1 wherein said emission surface is relatively flat.

4. The cathode as recited in claim 1 wherein said sites have at least two different electron affinities.

5. The cathode as recited in claim 1 wherein each said site is under 1 micron in diameter.

6. The cathode as recited in claim 1 wherein some of said low effective work-function material is amorphic diamond.

7. The cathode as recited in claim 1 wherein said emission sites each contain dopant atoms.

8. The cathode as recited in claim 7 wherein said dopant atoms are carbon.

9. The cathode as recited in claim 1 wherein said emission sites each have a plurality of different bonding structures.

10. The cathode as recited in claim 9 wherein one of said bonding structures is SP^3.

11. The cathode as recited in claim 1 wherein said emission sites each contain discontinuities in crystalline structure.

12. The cathode as recited in claim 11 wherein said discontinuities are point discontinuities.

13. The cathode as recited in claim 11 wherein said discontinuities are line discontinuities.

14. The cathode as recited in claim 11 wherein said discontinuities are dislocations.

15. A diamond film cold-cathode, comprising:
a substrate;
a layer of conductive material; and
a layer of amorphic diamond film deposited over said conductive material, said amorphic diamond film comprising a plurality of micro-crystallite electron emission sites.

16. The cathode as recited in claim 15 wherein at least some adjacent ones of said emission sites have discontinuous electrical properties.

17. The cathode as recited in claim 15 wherein said emission surface is relatively flat.

18. The cathode as recited in claim 15 wherein each said site is under 1 micron in diameter.

19. The cathode as recited in claim 15 wherein said emission sites contain dopant atoms.

20. The cathode as recited in claim 19 wherein said dopant atoms are carbon.

21. The cathode as recited in claim 15 wherein each of said emission sites have at least two different bonding structures.

22. The cathode as recited in claim 21 wherein one of said bonding structures is SP^3.

23. The cathode as recited in claim 15 wherein each of said emission sites have at least two different bonding orders.

24. The cathode as recited in claim 15 wherein said emission sites contain dopants other than carbon.

25. The cathode as recited in claim 15 wherein said emission sites contain defects in crystalline structure.

26. The cathode as recited in claim 25 wherein said defects are point defects.

27. The cathode as recited in claim 25 wherein said defects are line defects.

28. The cathode as recited in claim 25 wherein said defects are dislocations.

29. A method of operating a cathode, comprising the steps of:

causing an electrical current to flow through a layer of conductive material; and

directing said current through a layer of amorphic diamond film deposited over said conductive material, said amorphic diamond film comprising a

plurality of emission sites having discontinuous electrical properties.

30. A fluorescent light source, comprising:

a layer of amorphic diamond film deposited over a conductive filament, said amorphic diamond film comprising a plurality of electron emission sites, each electron emission site having a plurality of sub-regions; and

an anode surrounding said filament and said amorphic diamond film, said anode radiating light in response to receipt of electrons emitted by said electron emission sites.

AMENDED CLAIMS

[received by the International Bureau on 03 October 1994 (03.10.94);
Original claims 3,6 and 17 cancelled; original claims 1,15 and 29 amended;
remaining claims unchanged (4 pages)]

1. A cathode, comprising:

a layer of conductive material; and

a layer of amorphic diamond deposited over said conductive material, said amorphic diamond having a relatively flat emission surface comprising a plurality of distributed localized electron emission sites.

2. The cathode as recited in claim 1 wherein said emission sites have electrical properties which are discontinuous from each other.

3. [Cancelled]

4. The cathode as recited in claim 1 wherein said sites have at least two different electron affinities.

5. The cathode as recited in claim 1 wherein each said site is under 1 micron in diameter.

6. [Cancelled]

7. The cathode as recited in claim 1 wherein said emission sites each contain dopant atoms.

8. The cathode as recited in claim 7 wherein said dopant atoms are carbon.

9. The cathode as recited in claim 1 wherein said emission sites have a plurality of different bonding structures.

10. The cathode as recited in claim 9 wherein one of said bonding structures is SP^3.

11. The cathode as recited in claim 1 wherein said emission sites each contain discontinuities in crystalline structure.

12. The cathode as recited in claim 11 wherein said discontinuities are point discontinuities.

13. The cathode as recited in claim 11 wherein said discontinuities are line discontinuities.

14. The cathode as recited in claim 11 wherein said discontinuities are dislocations.

15. A diamond film cold-cathode, comprising:

a substrate;

a layer of conductive material; and

a layer of amorphic diamond film deposited over said conductive material, said amorphic diamond film having a relatively flat emission surface comprising a plurality of micro-crystallite electron emission sites.

16. The cathode as recited in claim 15 wherein at least some adjacent ones of said emission sites have discontinuous electrical properties.

17. [Cancelled]

18. The cathode as recited in claim 15 wherein each said site is under 1 micron in diameter.

19. The cathode as recited in claim 15 wherein said emission sites contain dopant atoms.

20. The cathode as recited in claim 19 wherein said dopant atoms are carbon.

21. The cathode as recited in claim 15 wherein each of said emission sites have at least two different bonding structures.

22. The cathode as recited in claim 21 wherein one of said bonding structures is SP^3.

23. The cathode as recited in claim 15 wherein each of said emission sites have at least two different bonding orders.

24. The cathode as recited in claim 15 wherein said emission sites contain dopants other than carbon.

25. The cathode as recited in claim 15 wherein said emission sites contain defects in crystalline structure.

26. The cathode as recited in claim 25 wherein said defects are point defects.

27. The cathode as recited in claim 25 wherein said defects are line defects.

28. The cathode as recited in claim 25 wherein said defects are dislocations.

29. A method of operating a cathode, comprising the steps of:

causing an electrical current to flow through a layer of conductive material; and

directing said current through a layer of amorphic diamond film deposited over said conductive material, said amorphic diamond film having a relatively flat emission surface comprising a plurality of emission sites having discontinuous electrical properties.

30. A fluorescent light source, comprising:

a layer of amorphic diamond film deposited over a conductive filament, said amorphic diamond film comprising a plurality of electron emission sites, each electron emission site having a plurality of sub-regions; and

an anode surrounding said filament and said amorphic diamond film, said anode radiating light in response to receipt of electrons emitted by said electron emission sites.

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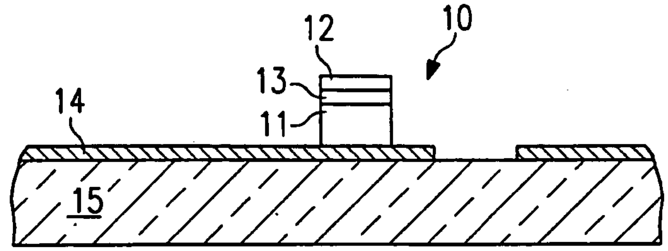

FIG. 1

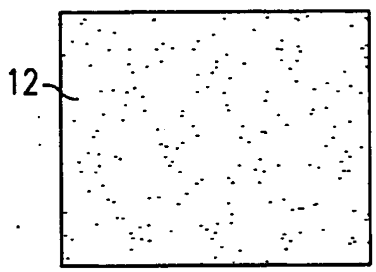

FIG. 2

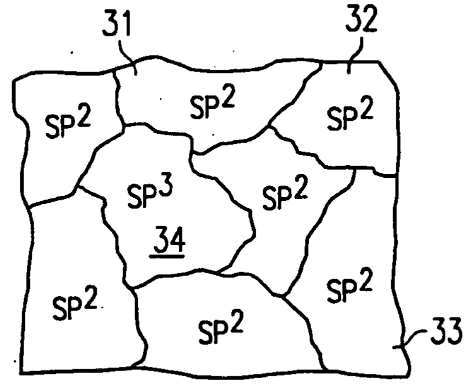

FIG. 3

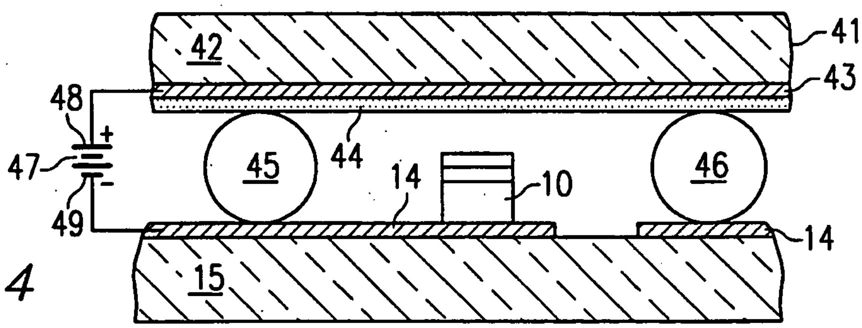

FIG. 4

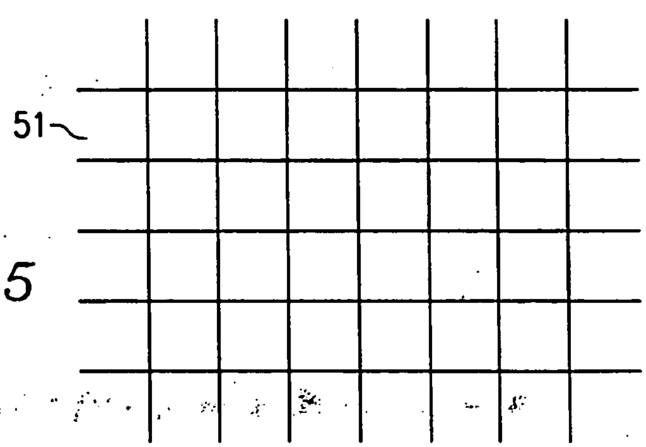

FIG. 5

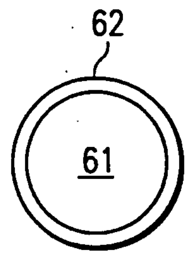

FIG. 6

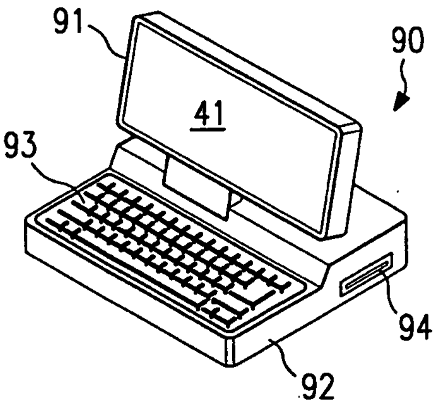

FIG. 9

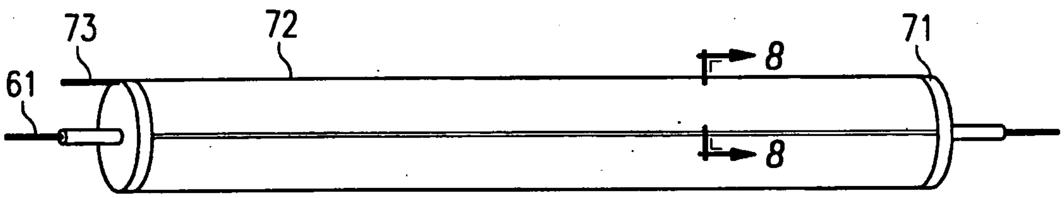

FIG. 7

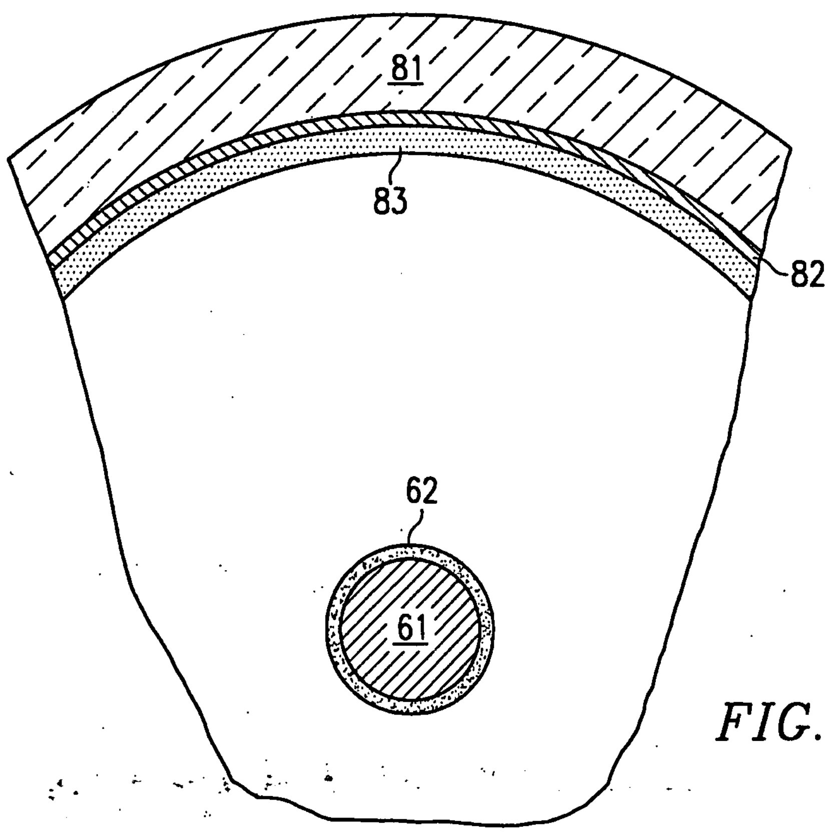

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/11845

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :HO1J/19/24
US CL :313/495
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 313/495, 496, 497, 308, 309, 336, 346R, 351; 315/169.4; 428/364, 367

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,141,460 (JASKIE ET AL.) 25 August 1992, Figs. 4A, 4C, 5D and 6A, 6C-6E; abstract, col. 1, lines 26-51, col. 2, lines 53-66, col. 3, line 15-col. 5, line14.	1, 2, 6, 15 and 29
A	US, A, 5,142,184 (KANE) 25 August 1992, Figs. 2C and 3; col. 2, lines 22-51	1, 5, 15 and 18
X	US, A, 4,663,559 (CHRISTENSEN) 05 May 1987, Figs 1 and 2; col. 2, lines 51-59; col. 3, line 64-col.4, line 5; col. 11, line 27-col.13, line2	1-4 and 11

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 23 MARCH 1994	Date of mailing of the international search report APR 18 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer ASHOK PATEL Telephone No. (703) 305-4934

Form PCT/ISA/210 (second sheet)(July 1992)★